One Hundred Consecutive Perfusions Over Five Hours

Jeffrey Peters and Michael Sparacino
Milwaukee Heart Surgery Associates, S.C.
Milwaukee, Wisconsin

Abstract

Complete surgical treatment of severe, diffuse coronary artery disease requires long perfusion time. We reviewed 100 consecutive perfusions longer than five hours (from a total of 675, operated May, 1980, through May, 1981). No case was excluded.

The 100 patients received 517 grafts, 217 coronary endarterectomies, 12 valves, and 12 aneurysmectomies; 98 had three vessel disease and 22 severe ventricular dysfunction. High flow, high pressure perfusion with physiologic blood gases was used.

Filters were used on cardiotomy return and arterial lines. Body temperature was kept 30–34°C at the preference of the surgeon. Intermittent ischemic arrest was used to preserve the myocardium. There were nine hospital deaths. Complications in the survivors included two instances of adult respiratory distress syndrome, one instance of stroke, and one of perioperative infarction. No patients were taken back for postoperative bleeding.

We conclude that, in view of the severity of disease, deaths and complications were well within acceptable limits.

Long perfusions, greater than five hours, did not contribute significantly to morbidity and mortality. Patients were perfused as long as necessary to achieve total revascularization.

Introduction

Adequate surgical treatment of severe, diffuse coronary artery disease requires relatively long perfusion time. Surgical technique has evolved to the point where placing nine grafts is practical. Where disease extends to the distal portion of an artery, endarterectomy is the only effective treatment. Perfusion technique must be adequate to allow patients to be perfused as long as necessary to achieve total revascularization, regardless of the extent of coronary artery disease.

To assess the adequacy of our perfusion technique, we reviewed all patients undergoing coronary bypass (combined procedures included) from May 1980 through May 1981. During this period, a total of 675 bypass procedures were done. For 100 of these patients, or 14.8%, cardiopulmonary bypass exceeded five hours. These 100 patients are the subjects of this report.

Surgical Details—Study Group

Table 1 describes the study group and procedures performed. The total number of bypass grafts was 517 (5.2 per patient). There were 217 (2.2 per patient) coronary endarterectomies.

Other operative procedures included: 9 aortic valve replacements, 3 mitral valve replacements, and 12 ventricular aneurysm resections. Seven of the cases were reoperations.

Table 2 describes the extent of disease. We define a "diseased" coronary as one with 70% or more reduction in luminal diameter. There were no patients with single vessel disease, 2 patients...
with double vessel disease, and 98 patients with triple vessel disease. Eighty patients had ejection fractions recorded before surgery. Thirty-eight (48%) patients exhibited normal left ventricular function (EF > 50%), 20 (25%) patients had moderate left ventricular dysfunction (EF 35-50%), and 22 (27%) patients had severe left ventricular dysfunction (EF < 35%).

**Perfusion Technique**

Table 3 is a summary of our perfusion technique and materials. All of the cases were perfused with double roller pumps, a hybrid bubble oxygenators, 20 micron screen arterial line filter, packed dacron + 20 micron screen cardiotomy filter, and silicone rubber pump headers 5/8 inch internal diameter.

The prime solution consisted of 3,000 milliliters of balanced electrolyte solution, adjusted to pH 7.4. 5,000 units of heparin, and 25 grams of sodium mannitol. Gravity drainage was from both vena cavae; return was into the ascending aorta through a 9.5 mm. rigid disposable cannula. The heart was vented for left ventricular decompression via cannulation in the aortic root.

Body temperature was maintained at between 30 and 34°C (rectal). Units of additional solutions added to the perfusate during bypass averaged (per patient): whole blood, 2.0; packed cells 0.77, albumin 0.61. Total blood products added averaged 3.4 units per patient. In addition to the blood products, an average of 5 liters of crystalloid were added.

Mean arterial pressure averaged 80 mmHg with a standard deviation (S.D.) of 10 mmHg. The mean perfusion flow rate was 67 ml per kilogram body weight per minute with a standard deviation of 9 ml. Arterial blood gas data revealed a mean pH of
7.37 ± .04 S.D., and a mean \( pO_2 \) of 170 ± 42 mmHg S.D. (We believe 170 mmHg \( pO_2 \) is not physiologic\(^5\), and are now beginning to use a membrane oxygenator for better control of \( pO_2 \).) The mean \( pCO_2 \) was 40 ± 3 mmHg, and hematocrit 24% mean, ±2%. Average total urinary output on pump was 3,725 milliliters ± 2,325 milliliters; mean perfusion time was 5 hours, 42 minutes or 342 minutes.

**Results**

Table 4 summarizes the deaths and complications. There were nine surgical deaths, all attributed to low cardiac output. The intra-aortic balloon pump was used on eight of the persons who died. In addition to these nine, three other patients required the intra-aortic balloon pump. The only other complications were two instances of adult respiratory distress syndrome and one instance of perioperative myocardial infarction. No patients were returned to surgery for postoperative bleeding. These death and complication rates are well within acceptable limits for patients with far advanced and severe coronary artery disease.\(^6\)

**Discussion & Summary**

These data strongly suggest that long perfusions do not per se contribute significantly to morbidity and mortality. This is not to be confused with long perfusion necessitated because of technical difficulties. Overall statistics for all 675 bypass patients operated on during the study period were as follows: 48.5% received coronary endarterectomy, 23.7% were second reoperations, and an average of 3.9 bypass grafts were placed. Average perfusion time was 250 minutes.

Of the 304 patients who had ejection fractions recorded before surgery, 150 (49%) had normal left ventricular function (EF > 50%); 78 (26%) had moderate dysfunction (EF < 35–50%); and 76 (25%) severe left ventricular dysfunction (EF < 35%). Surgical (30 day) mortality was 5.0%.

The overall statistics between the study group and all patients operated during the same time period show similar results, except that 81% of the study group, versus 48% of all patients, received coronary endarterectomy. The study group averaged 5.2 grafts per patient versus 3.9 for all patients. Surgical mortality was 9% in the study group and 5% for all patients. Severe, diffuse disease is associated with higher surgical mortality.

Nevertheless, we have shown that patients with severe disease can be perfused as long as necessary to achieve the total revascularization. Factors we believe are important in successful long perfusion are summarized in Table V and discussed as follows:

*Physiologic blood flows and pressures* This is particularly important in preventing cerebral complications, because these patients have atherosclerosis to some extent throughout their bodies. We perfuse chronic hypertensives at higher pressures. The effectiveness of cardioplegia is frequently compromised by high flows and pressures, which accelerate the removal of the cardioplegic agent through non-coronary collateral.\(^7\) This is one of the reasons we do not use cardioplegia.

*Hematocrit 22–24%* This is the only variable we intentionally allow to go out of the physiologic range. As the hematocrit drops, so does blood viscosity. This allows more flow for a given pressure and adequate oxygen delivery is maintained. If the hematocrit drops below 20%, the viscosity changes little but the oxygen carrying capacity decreases markedly.\(^8\) From our experience, we have found that 22–24% is adequate to deliver oxygen yet low enough to minimize use of homologous blood.

**Table 4**

<table>
<thead>
<tr>
<th>Deaths and Complications</th>
<th>Fatal</th>
<th>Non-Fatal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Cardiac Output</td>
<td>9</td>
<td>3*</td>
</tr>
<tr>
<td>Major Stroke</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Adult Respiratory Distress Syndrome</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Perioperative Myocardial Infarction</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Reoperation for Bleeding</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>* Requiring Intra-aortic Balloon Pump</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 5**

<table>
<thead>
<tr>
<th>Technique Summary—Important Points</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. High Flow Rates</td>
<td>60–80 cc/kgm/min</td>
</tr>
<tr>
<td>2. High Arterial Pressure</td>
<td>80 mmHg*</td>
</tr>
<tr>
<td>3. Physiologic Blood Gases</td>
<td>pH 7.40, ( P0_2 )</td>
</tr>
<tr>
<td></td>
<td>100–125 mmHg, ( PCO_2 ) 40–45 mmHg</td>
</tr>
<tr>
<td>4. Hematocrit</td>
<td>22–24%</td>
</tr>
<tr>
<td>5. Arterial and Cardiotomy Filters</td>
<td></td>
</tr>
<tr>
<td>6. Changes Only of Proven Benefit</td>
<td></td>
</tr>
</tbody>
</table>

\* Higher Mean Pressure for Hypertensive Patients
Physiologic blood gases With the maintenance of physiologic flows and moderate hematocrit, little or no lactic acid accumulates and pH is maintained. This series represents about 550 hours of perfusion. Not one ampule of bicarbonate was added on bypass, yet the pH was maintained at \( 7.37 \pm \frac{1}{4} \). A drop in pH indicates inadequate perfusion and should be corrected by increasing flow, not adding buffer.

We prefer to keep the pCO\(_2\) on the high side of 40 mmHg. Low pCO\(_2\) causes a reduction in cerebral flow, and we know of no detrimental effects of a slightly elevated pCO\(_2\). In this study our average pCO\(_2\) was 40 mmHg. We would prefer to keep the pCO\(_2\) at a minimum of 40 mmHg. Our preferred range of pO\(_2\) is 100–140 mmHg, primarily because of the coronary vasoconstrictive effects of elevated pO\(_2\) but also because we try to avoid operating outside of the physiologic range without good reason. In this study, the pO\(_2\) averaged 170 mmHg; we would prefer a maximum of 170 mmHg.

It appears that there is simply no way to attain the blood gas levels we consider ideal; not with currently available gas interface oxygenators (except, of course, by mixing nitrogen with the O\(_2\)). Therefore, we have started evaluating membrane oxygenators. They show great promise of improved control of blood gases.

Cardiotomy and arterial line filters Use of filters is based on the fact that the largest formed element in blood is 13 microns. Anything larger is not blood and should be removed. We have used filters since their introduction and feel that they are an essential element in keeping cerebral and lung complications low.

Making changes to the system only after benefit has been proven We do not evaluate a change unless it holds the promise of a significant improvement. Similarly, we do not adopt a change unless we are convinced that it is better than the way we were doing it before. Minor and seemingly insignificant changes, especially when allowed to amass, can deteriorate the performance of a system.

Intermittent ischemic arrest Regardless of how well the body is perfused, it is to no avail if the heart will not eventually take over. Our perfusion technique and myocardial protection technique or intermittent ischemic arrest—work hand in hand. Non-coronary collateral circulation can remove cardioplegic solution from the heart necessitating reduction in systemic flow. Physiologic flow, pressure, pO\(_2\), and maintenance of rhythm during reperfusion are key and essential elements to the success of intermittent ischemic arrest. This perfusion technique is used for mitral valve replacements as well. During aortic valve replacement coronary perfusion is employed to fill the requirements of intermittent ischemic arrest.

Summary

From our experience, a prolonged cardiopulmonary bypass time, associated with major revascularization and/or combined procedures did not contribute to the overall operative risk. We attribute these results, in part, to the adequacy of perfusion.

References